OBSERVATIONS ON THE ANATOMY OF THE THEBESIAN VESSELS OF THE HEART.*

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THOUGH the existence of small channels—usually termed the Thebesian veins—connecting the coronary vessels with the chambers of the heart was first recorded by Vieussens[16] in 1706, our knowledge of their anatomy remains scanty. Lannelongue[9] has shown that from endocardial foramina in the auricles, small vessels arise that connect these foramina to each other, and unite with the coronary veins and also with the capillary network in the auricular myocardium. As will be seen from the historical accounts given by Pratt[13] and Wearn[17], the statements in past writings about similar channels in the ventricles are in many respects contradictory. While some writers hold that in the mammalian† heart there are Thebesian vessels in the ventricle like those in the auricle, others[3, 9, 11, 15] deny their existence and others again[1, 17] maintain that they are in communication not only with the coronary veins but also more or less directly with the coronary arteries through channels larger than capillaries.

So far as we are aware there is as yet no sufficient account of the anatomy of these vessels in the ventricle. The most complete is that by Langer[8]; to this we have a good deal to add.

We have examined a series of 44 mammalian hearts, 12 human, 4 from sheep and 28 from dogs ; our findings in the three types need not be described separately since they are in essentials the same.

Methods. To demonstrate the Thebesian vessels we have injected them through their endocardial foramina and through the coronary vessels. The injection masses chiefly used were chrome yellow gelatine of various thicknesses and Huber's[7] celloidin, the injected hearts, or portions of them,

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* Work undertaken on behalf of the Medical Research Council.

† Communications are also present between the coronary vessels and the ventricular cavity in the hearts of certain fishes[12] and reptiles, but not of the amphibia[6].

being subsequently either cleared in methyl salicylate or digested in 75 per cent. hydrochloric acid. We have found injection to succeed best as a rule in fresh tissues and after coronary perfusion with warm physiological saline. To inject the Thebesian vessels we have used a series of finely drawn glass cannulæ of such sizes as to fit snugly into the endocardial foramina. The perfused and opened heart, or more coveniently a portion of it, is immersed in warm saline ; the endocardium is examined and injection carried out under the binocular microscope. A cannula of suitable size, filled by suction through a rubber tube held in the mouth (thus avoiding the entrance of particles too large to be subsequently expelled through its fine nozzle) is inserted into a foramen and the mass is blown into the vessels. During injection the field of view is kept clear of backward escaping injection mass by a stream of warm saline controlled by an assistant. To avoid material escape from the vessels when injection is finished the site of injection is frozen with an ethyl chloride spray and the heart is at once placed in iced formalin.

The injecting pressure used is low, the measured pressure within the cannula itself being no more than 50 to 60 mms Hg. ; nevertheless, while all risk of extravasation is avoided complete and widespread injections are obtained with regularity.

When the vessels were injected with celloidin, the specimen was removed from the hydrochloric acid as soon as the tissues were softened, usually after 24 to 48 hours. The specimen was immersed in water and observed under the binocular microscope while the softened tissues were washed away piecemeal by means of a fine jet of water ; thus the situation and distribution of the injected vessels were followed through the heart wall.

In the case of injections made through the coronary vessels, the endocardial aspect of the ventricles was watched through incisions, the right ventricle being laid open anteriorly through the pulmonary artery and the left ventricle down its posterior wall ; the cut margins were sealed either with bowel clamps or by a series of interrupted overlapping sutures. In this way filling of subendocardial vessels and the issue of injection mass from the Thebesian foramina were followed during injection.

Thebesian foramina. As Langer[8] noted, not all the small foramina in the endocardium are the mouths of Thebesian vessels ; some are but blind outpouchings while others are the orifices of intertrabecular spaces. Thebesian foramina are to all appearances nothing but the mouths of intertrabecular spaces ; they can often be distinguished, however, by their small size and by the fact that under the binocular microscope, and sometimes even with the naked eye, the vessels arising from them may be seen for a part of their course under the endocardium in the uninjected heart as is shown in Fig. 1. The larger foramina measure about 1 mm. in diameter, the smaller are barely visible to the naked eye ; the details of their structure can only be seen clearly under the dissecting microscope. They are most easily recognised in the smooth portions of the heart wall, in the trabeculated areas

they are often hidden beneath the muscle bundles and are only displayed by dissection. Sometimes slit-like, they are as a rule circular in outline. They may be funnel shaped and lead directly into vessels passing vertically into the myocardium. Usually, however, the vessels run tangentially under the endocardium or obliquely into the muscle and the orifice is partly surrounded and often narrowed by a delicate falciform fold of endocardium. Frequently, several vessels arise from a single endocardial foramen as is seen in Fig. 1. Again, a Thebesian vessel may arise from the end of a groove or furrow between adjacent muscle bundles, the vessel at its commencement appearing to be but the continuation of the furrow roofed over by endocardium.

Though Thebesian orifices are to be found in all parts of the four chambers they are most constantly present on the interauricular and interventricular septa, specially on the right side, and on the papillary muscles of the left ventricle, but their number and situation here as elsewhere in the heart wall are very variable. Thus, in one dog's heart, 9 foramina were found and injected in the left ventricle, 1 at the base of the anterior papillary muscle, 1 near the apex of the posterior papillary muscle, 3 behind the posterior flap of the mitral valve, 3 about the middle of the septum and 1 under the trabeculæ at the apex. In the same heart, 21 were found in the right ventricle, 8 among the trabeculæ of the lateral wall, and 13 on the septum, 6 of these being in the conus region. In another dog's heart, none at all were found in the left ventricle and only 11 in the right ventricle, 5 being distributed over the lateral wall and 6 on the septum. Again, in one human heart, we found 2 in the left ventricle on the septum and 10 in the right ventricle, 5 being on the septum; in another human heart, 4 were noted in the left ventricle, 2 being at the base of the posterior papillary muscle, 1 on the anterior wall and 1 behind the posterior mitral flap; 2 were found in the right ventricle of the same heart, 1 in the middle of the lateral wall and 1 under the septal flap of the tricuspid valve. In Fig. 7, 11 Thebesian orifices and the vessels injected from them are shown on the right side of the interventricular septum of a sheep's heart.

Examination and dissection of injected preparations reveals a complex arrangement of vessels arising from the endocardial foramina. Briefly it may be said, that some of the vessels run for a shorter or longer distance under the endocardium and in the adjacent musculature, others at once penetrate deeply into the heart wall; some quickly subdivide and form a tree ending in a capillary network continuous with that of the coronary vessels, while others unite more or less directly with vessels from neighbouring foramina and with the coronary veins. For convenience, three main types of vessel may be described, namely, (1) Thebesian trees; (2) Thebesian inter-communicating vessels; and (3) Thebesian-coronary communicating vessels.

Though the descriptions and illustrations that follow refer to the ventricular vessels, they also hold good for auricular vessels.

Thebesian trees. Examples of Thebesian trees are given in Figs. 3, 4 and 5. The one shown in Fig. 3 is from the left ventricle of a human heart; the orifice 0·3 mms in diameter being situated on the septum 2 cms below the aortic cusps. The vessels ramify under the endocardium and in the adjacent muscle. A corrosion preparation of a similarly situated tree also from a human heart is illustrated in Fig. 4. Fig. 5 shows a papillary muscle from a dog's left ventricle; from the endocardial foramen situated about the middle of the muscle and indicated by the arrow head two vessels arise which quickly subdivide and end in a capillary network extending throughout the greater part of the papillary muscle. Such trees are to be found in all parts of the heart wall, in both auricles and ventricles. They vary considerably in size; thus, in the human hearts examined the larger trees covered areas of about 2 cms in diameter and the smaller ones no more than 3 or 4 mms. In the case of the small trees the endocardial orifices are correspondingly minute; in one instance a tree covering an area of 3 mms diameter arose from an orifice 0·1 mm. wide.

Thebesian inter-communicating vessels. Not only do the vessels arising from one orifice anastomose with each other but also neighbouring orifices are in free communication through channels running both superficially under the endocardium and deeply in the muscle. Small anastomoses between branches of a Thebesian tree are to be seen in Fig. 4 and numerous anastomoses both large and small, giving rise to a plexus of vessels in the myocardium, are shown in Fig. 12. Attention may also be drawn to the curiously shaped plexus formed by the vessels arising from the foramen *e* in Fig. 10. Communications between neighbouring foramina are to be seen in Fig. 7 and in greater detail in Figs. 9 and 10. On the right side of the interventricular septum of the sheep's heart illustrated in Fig. 9, chrome yellow gelatine was injected into the Thebesian orifice *a* and, filling the vessels arising from it, issued from the neighbouring orifices *b* to *f*. The more superficial channels of communication are clearly visible in the figure; the deeper channels, such as that between *a* and *b*, are not seen. Fig. 10 shows a wide channel joining three foramina *a*, *b* and *d* in the dog's heart; a fourth foramen *c* is connected by two finer vessels.

Thebesian-coronary communications. Just as the Thebesian vessels communicate freely with each other, so they anastomose freely with the coronary veins and by channels of all sizes; they do not communicate with the coronary arteries except through the capillaries. While the coronary veins on the surface of the heart may be injected from the Thebesian orifices even when fairly thick masses are used, the coronary arteries are not filled unless the mass is sufficiently fine to pass through capillaries and in all our specimens where the surface arteries have been injected from the Thebesian orifices areas of capillary filling have been found in the cleared preparation. Whenever both coronary arteries and veins have been filled by Thebesian injection the veins have been injected much more completely

and extensively than the arteries and we have failed to find any communications other than capillaries between the arteries on the one hand and the veins and Thebesian vessels on the other, though Thebesian and coronary vein anastomoses are constantly present.* Thebesian-coronary anastomoses are illustrated in Figs. 2, 3, 6, 7, and 8. Though coronary veins injected from a Thebesian foramen are shown in Fig. 5, the actual communicating branches are not seen, being deep in the papillary muscle. In Fig. 3 a very small coronary vein is seen arising from the margin of the tree to the extreme right of the figure. In Fig. 6, showing the papillary muscle of a dog's left ventricle, the coronary veins of the muscle were injected through the Thebesian vessel *a*; the subendocardial ramifications of the coronary veins are seen at *b* and *c* and at *b*, at the apex of the papillary muscle, the Thebesian vessel anastomoses with the coronary veins. The communication with the surface coronary vein *d* is not visible. In Fig. 7 two Thebesian-coronary communicating vessels are seen. A large vessel opening into the ventricle by two endocardial foramina *a* and *b* runs subendocardially to the apex of the heart where it pierces the ventricular wall to join with the anterior interventricular vein; this vessel is shown in greater detail in Fig. 8. The smaller communicating vessel, *p*, runs in the muscle of the septum from the orifice *n* to join a coronary vein at the root of the aorta. A corrosion preparation of an anastomotic vessel situated similarly to the last and also in the sheep's heart is shown in Fig. 2. One of the vessels B injected from the orifice A was traced up the right side of the septum to join with the coronary vein C at the root of the aorta.

Injections through the coronary vessels lead to the same conclusions as to the nature of the Thebesian-coronary communications. Our observations may be summarised as follows :—

(*a*) Physiological saline injected into the arteries or veins at low pressure, 20 to 50 mms Hg., issues freely from Thebesian orifices in both ventricles.

(*b*) Chrome yellow gelatine, found by experiment to be sufficiently thin to pass through capillaries, and similarly injected into either arteries or veins also issues freely from the Thebesian orifices and enters in addition either the veins or the arteries respectively.

(*c*) Chrome yellow gelatine too thick to pass through capillaries, when injected into the coronary arteries at a pressure of 150 mms Hg. does not escape into the ventricles nor does it enter the coronary veins; the same mass injected into the coronary veins at pressures of 20 to 50 mms Hg. issues freely from the Thebesian orifices but does not pass into the arteries.

(*d*) Huber's celloidin injected into the arteries at a pressure of 150 mms Hg. does not enter the ventricles; injected into the veins under a pressure of 50 mms Hg. it issues freely from Thebesian orifices.

* We may add that in all cases of doubt in the cleared preparation as to the nature of the coronary vessel injected from the Thebesian vessels, the question has been decided by histological examination of blocks of tissue excised from them.

Fig. 11 shows a corrosion preparation of a coronary vein *a* on the lateral wall of the left ventricle of a human heart. Two venous branches open into the ventricular cavity and the injection mass, issuing among the trabeculæ, formed the celloidin plugs *b* and *c*.

(*e*) We have also used a gelatine mass containing lycopodium spores stained with gentian violet. The stained spores are roughly spherical in shape and are very even in size, their diameter varying in our sample between 27 and 33 μ, the average being 30 μ or 4 times the size of a red blood corpuscle. This mass fails to appear in the ventricles when injected into the arteries under a pressure of 150 mms Hg., but the stained spores can be seen to issue from some of the Thebesian foramina when the mass is injected into the veins at a pressure of only 50 mms Hg..

It seems clear from these observations also that though the communication between the coronary veins and the ventricular chambers is free and runs through channels larger than capillaries, arterial communication is restricted to capillaries. We have been unable to find evidence of the normal occurrence of the more direct arterial communications described by Abernethy[1] and Wearn.[17] It may be remarked, however, that three instances are known of abnormal communications between the coronary arteries and the cavity of the ventricle. A direct communication between the left coronary artery and the left ventricle in an ox heart is recorded by Reid[14] and in a human heart by Blakeway[2] and one of us[5] has described an anomalous child's heart in which the coronary arteries and veins opened freely into the intertrabecular spaces of a common ventricle.

We have thus seen that, of the vessels opening into the ventricle through the Thebesian foramina, some are in the form of more or less independent trees arising from the myocardial capillary network; some are channels joining neighbouring orifices together and some communicate more or less directly with the coronary veins. It is to be said, however, that the three types merge into each other and that there are all gradations between them and an extremely complex arrangement of branching and anastomosing channels that may be best described as a myocardial plexus arising from the capillaries and opening on the one hand into the superficial coronary veins and into the cavities of the ventricles on the other.

Two further points remain to be noted. The first is in regard to the channels passing from a Thebesian orifice to a superficial coronary vein. In some instances these are accurately described as anastomoses between a Thebesian vessel and a coronary vein, each vessel diminishing in calibre from its mouth to the region of union and the branches of each being directed principally towards the mouth. In others, however, as in those illustrated in Figs. 8 and 11, the channels may be regarded anatomically rather as branches of coronary veins opening into the ventricle, there being no clear indication of a union of two vessels of different origin.

The second point is in regard to the channels joining neighbouring endocardial orifices. In some instances these also are correctly described as vascular anastomoses as, for example, those uniting orifices *a* and *e* in Fig. 9, others, however, are more like intertrabecular spaces than definite vessels. Thus in Fig. 10, the short unbranched channel between *d* and *f* would be called a small intertrabecular space, so also might the channel between *a* and *b*, while the channel between *a* or *b* and *d* might be regarded anatomically either as a wide Thebesian vessel or a long and narrow intertrabecular space. There are in fact all gradations between the short and wide spaces between the muscle trabeculæ and definite vessel-like channels in the inner aspect of the heart wall.

This discription of the anatomy of the vessels arising from the Thebesian foramina and of their relations with the coronary veins and arteries on the one hand and with the intertrabecular spaces on the other is in agreement with what is known of the embryology of the blood supply to the heart.[4, 10] The myocardial vessels in the developing heart are derived from inward extensions of the coronary veins and outward extension of the intertrabecular spaces, the two systems uniting with each other ; the coronary arteries arise later and join the capillary network already formed by the venous and the intertrabecular outgrowths. The intertrabecular portion of this system forms the Thebesian vessels of the adult heart.

Summary.

1. The Thebesian vessels, specially of the ventricles, have been examined in a series of mammalian hearts injected with gelatine and celloidin masses.

2. Three main types of vessels arising from the Thebesian foramina are described ; the three types merge into each other.

    (*a*) Vessels subdividing into trees ending in a capillary network and ramifying in the endocardium and underlying muscle.

    (*b*) Channels uniting neighbouring foramina and showing all variations from fine anastomoses between neighbouring trees and intertrabecular spaces.

    (*c*) Vessels uniting foramina with coronary veins and showing all variations from fine anastomoses between Thebesian tree and coronary vein to direct communication of the coronary vein with ventricle.

3. The coronary arteries communicate with the Thebesian vessels only through capillaries.

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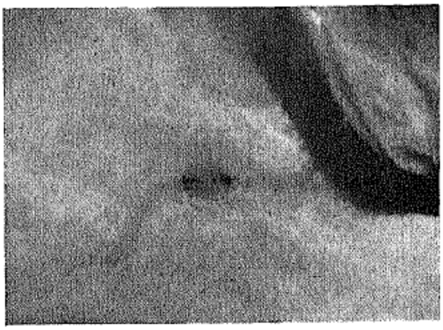

Fig. 1. Photograph (× 7) of a Thebesian foramen in the conus region of the ventricular septum of a dog's heart. The foramen is a cup-shaped depression in the endocardium and from it two main vessels pass subendocardially, one to the right and the other to the left. The course of these vessels is indicated by faint shadows proceeding from the foramen and their mouths are partly surrounded by falciform endocardial folds. Between the mouths of these two main vessels, three smaller ones open into the myocardium, two by slit-like mouths lying immediately to the right of the left hand vessel and one by a minute circular orifice lying immediately to the left of the right hand vessel.

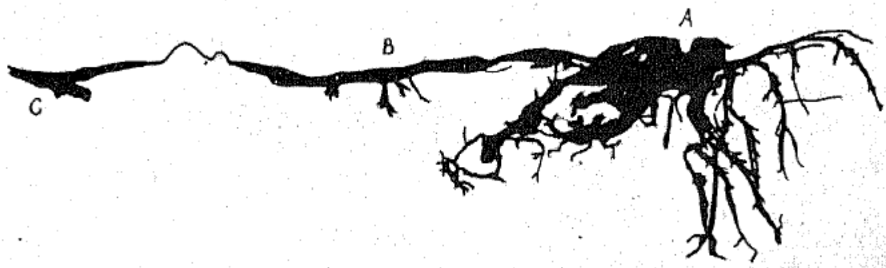

Fig. 2. Photograph (× 10) of a corrosion preparation (surface view) of colloidin injected Thebesian vessels from the interventricular septum of a sheep's heart. From the orifice A, situated in the conus region, a number of vessels arise and during preparation of the specimen were seen to ramify subendocardially and in the underlying muscle. The branch B passed up the right side of the septum in the muscle to communicate with a coronary vein C at the root of the aorta.

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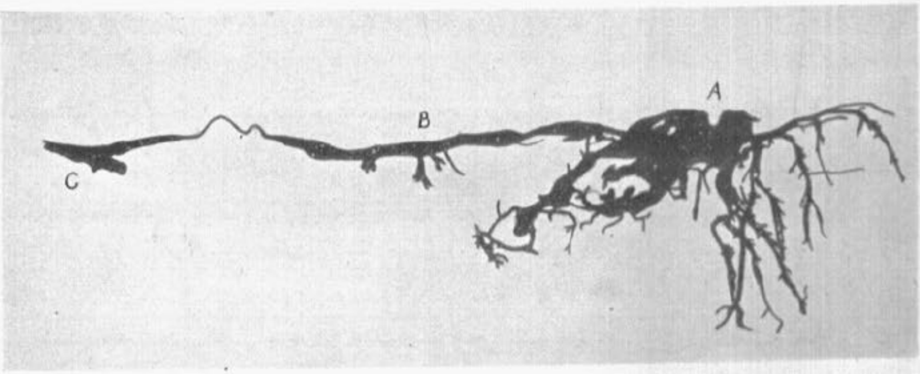


Fig. 2. Photograph ($\times 10$) of a corrosion preparation (surface view) of celloidin injected Thebesian vessels from the interventricular septum of a sheep's heart. From the orifice A, situated in the conus region, a number of vessels arise and during preparation of the specimen were seen to ramify subendocardially and in the underlying muscle. The branch B passed up the right side of the septum in the muscle to communicate with a coronary vein C at the root of the aorta.

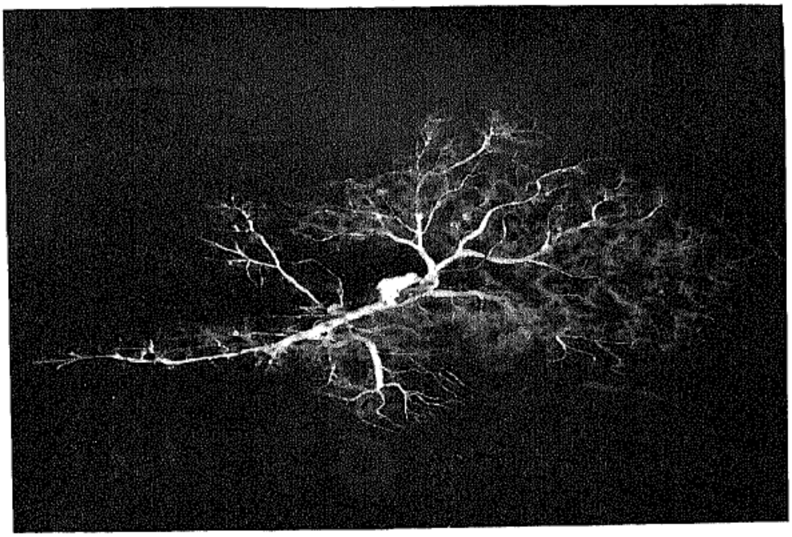
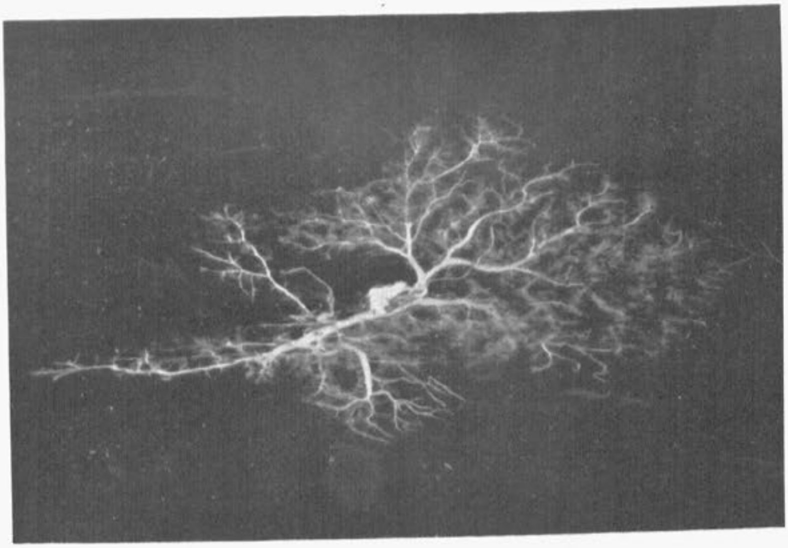


Fig. 3. Photograph (× 5) of a cleared preparation of the left side of the interventricular septum of a human heart showing a Thebesian tree. The vessels were all injected with chrome yellow gelatine through the foramen in the middle of the tree. A very small coronary vein arising from the margin of the tree is seen to the extreme right of the figure.

Fig. 4. Photograph (× 7·5) of corrosion preparation (surface view) of a colloidin injected Thebesian tree from the left side of the interventricular septum of a human heart. The site of injection is indicated by the arrow head.



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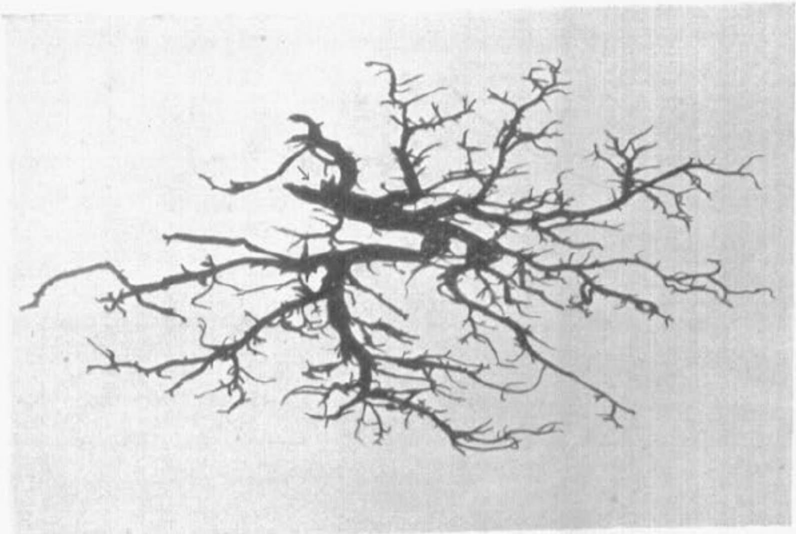

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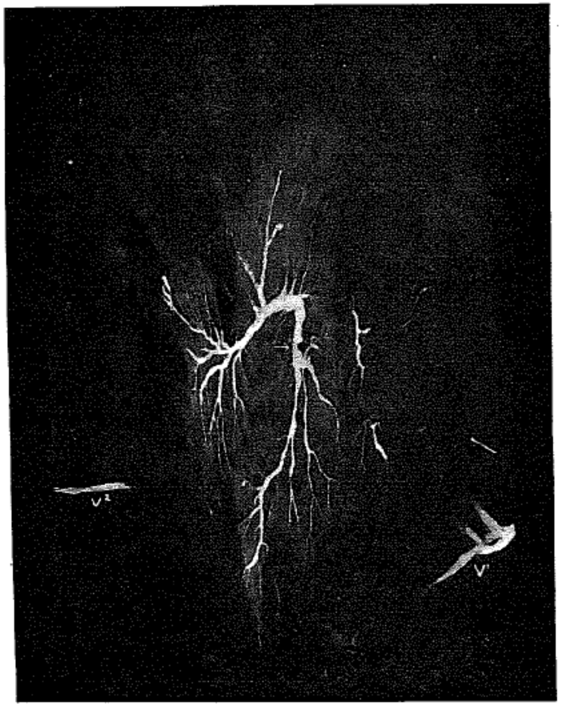

Fig. 5.

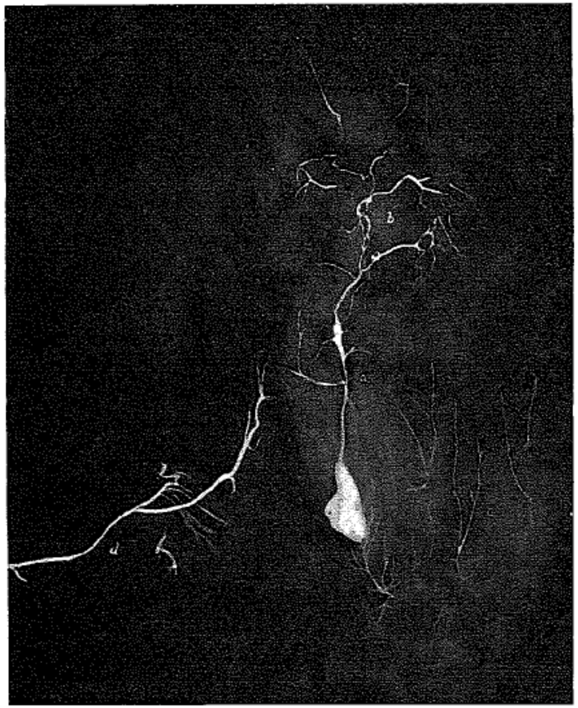

Fig. 6.

Fig. 5. Photograph (× 3·5) of a cleared preparation of a papillary muscle from the left ventricle of a dog's heart showing a Thebesian tree. The orifice through which the vessels were injected with chrome yellow gelatine is shown by the arrow head in the centre of the figure. V^1 and V^2 are coronary veins on the surface of the heart filled from the Thebesian vessels. The muscle overlying the coronary veins has been partly removed to bring them into view; the actual communicating channels are not seen.

Fig. 6. Photograph (× 4) of cleared preparation of papillary muscle from left ventricle of a dog's heart showing vessels injected from a Thebesian orifice. The orifice and the groove from which it arises is filled by a plug of injection mass. Through the superficial vessel *a* and other deep branches not seen, the coronary veins of the papillary muscle have been filled; the subendocardial ramifications of the veins are seen at *b* and *c*; at *b* are anastomoses between the superficial Thebesian vessel and the coronary veins. *d* is a coronary vein passing from the papillary muscle through the wall of the left ventricle to the surface of the heart, and also filled through the Thebesian vessels. The overlying muscle has been partly removed to bring this vein into view.

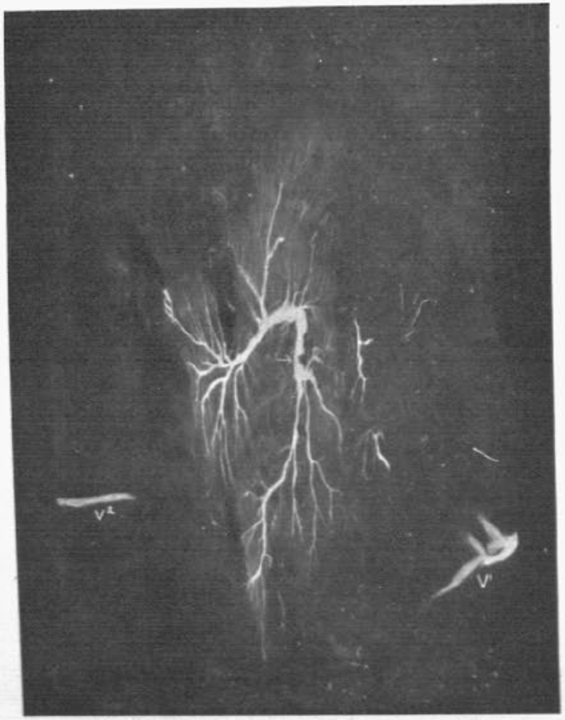

Fig. 5.

Fig. 6.

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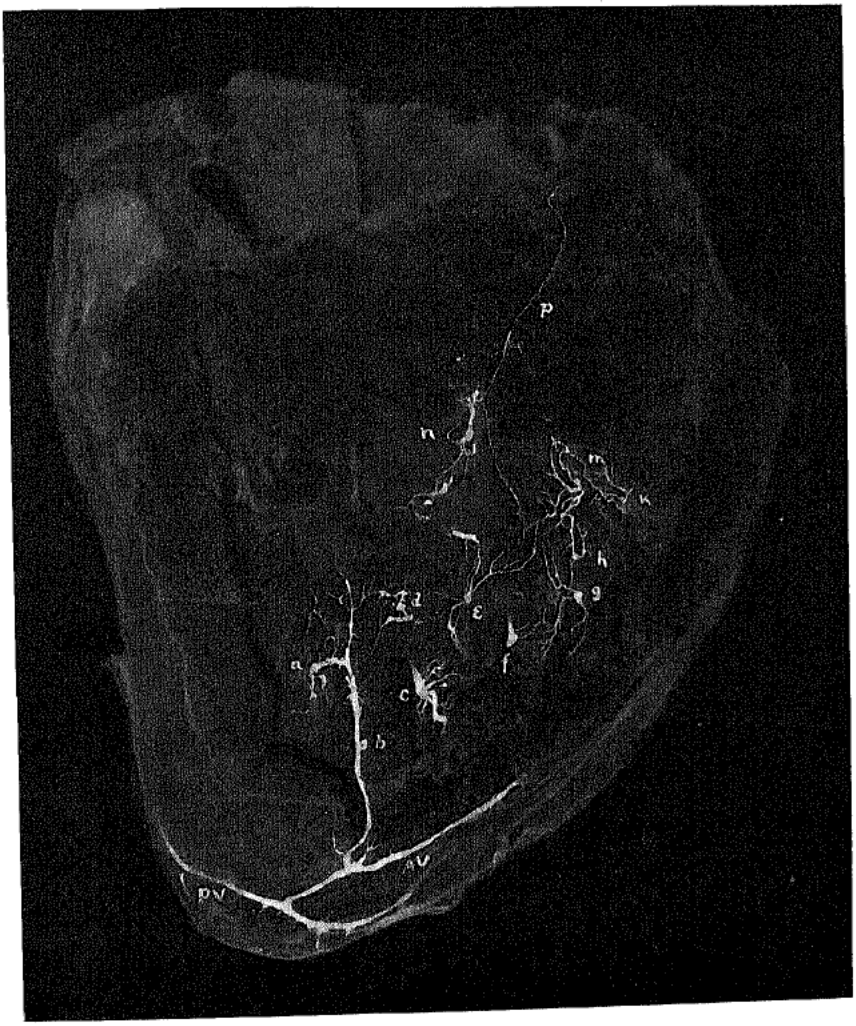


Fig. 7. Photograph (×2) of a cleared preparation of the right side of the interventricular septum of a sheep's heart showing 11 Thebesian orifices (*a* to *n*) and vessels injected from them. Only the larger and more superficial vessels are clearly in view except where the upper portion of the septum has been dissected away to show the vessel *p* running in the muscle from the orifice *n* to communicate with a coronary vein at the root of the aorta. The large Thebesian vessel with orifices *a* and *b* runs subendocardially to the apex and there pierces the wall of the right ventricle to join with an anterior interventricular vein (AV) which in turn unites with a posterior interventricular vein (PV). The vessels from neighbouring orifices anastomose with each other.

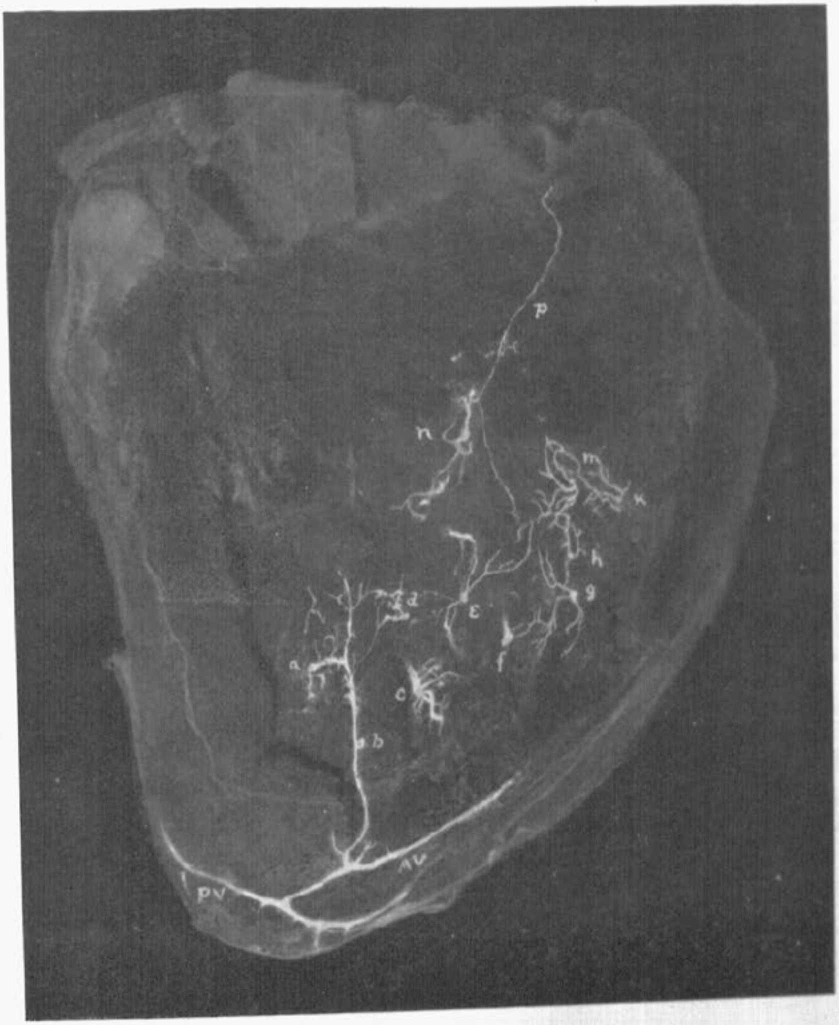


Fig. 7. Photograph ($\times 2$) of a cleared preparation of the right side of the interventricular septum of a sheep's heart showing 11 Thebesian orifices (a to n) and vessels injected from them. Only the larger and more superficial vessels are clearly in view except where the upper portion of the septum has been dissected away to show the vessel p running in the muscle from the orifice n to communicate with a coronary vein at the root of the aorta. The large Thebesian vessel with orifices a and b runs subendocardially to the apex and there pierces the wall of the right ventricle to join with an anterior interventricular vein (AV) which in turn unites with a posterior interventricular vein (PV). The vessels from neighbouring orifices anastomose with each other.

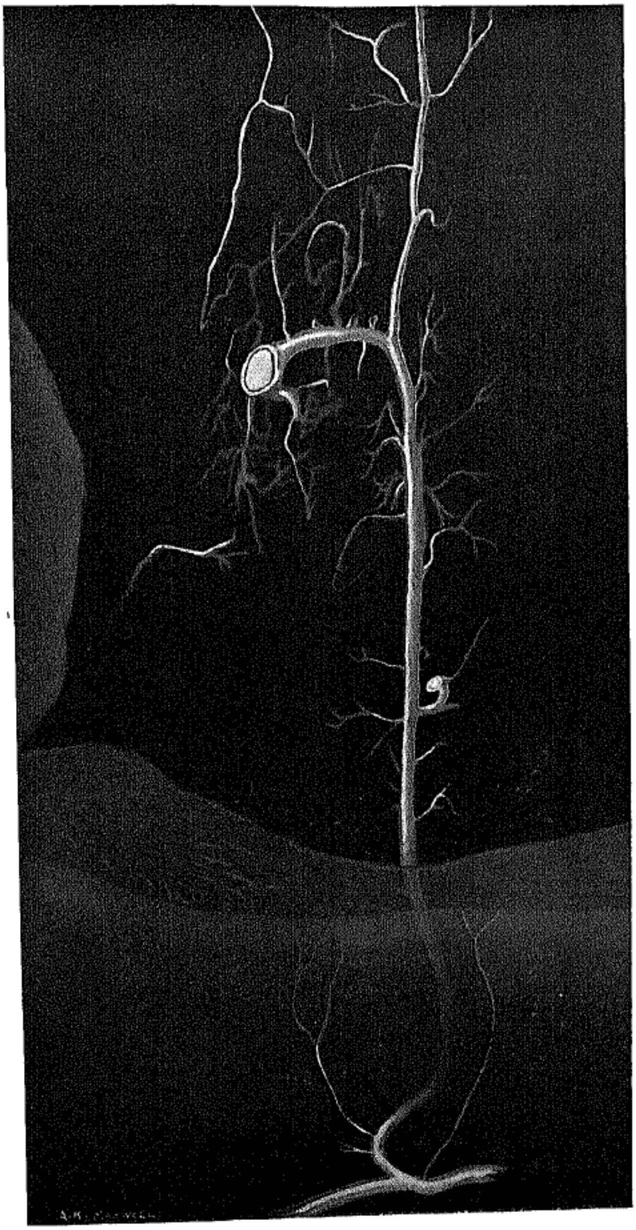


Fig. 8. A drawing (× 10) of the large Thebesian vessel and its branches in a sheep's heart shown in Fig. 7. The vessel has two openings on the right side of the septum and runs subendocardially to the apex of the heart and pierces the wall of the right ventricle to join with an anterior interventricular vein.

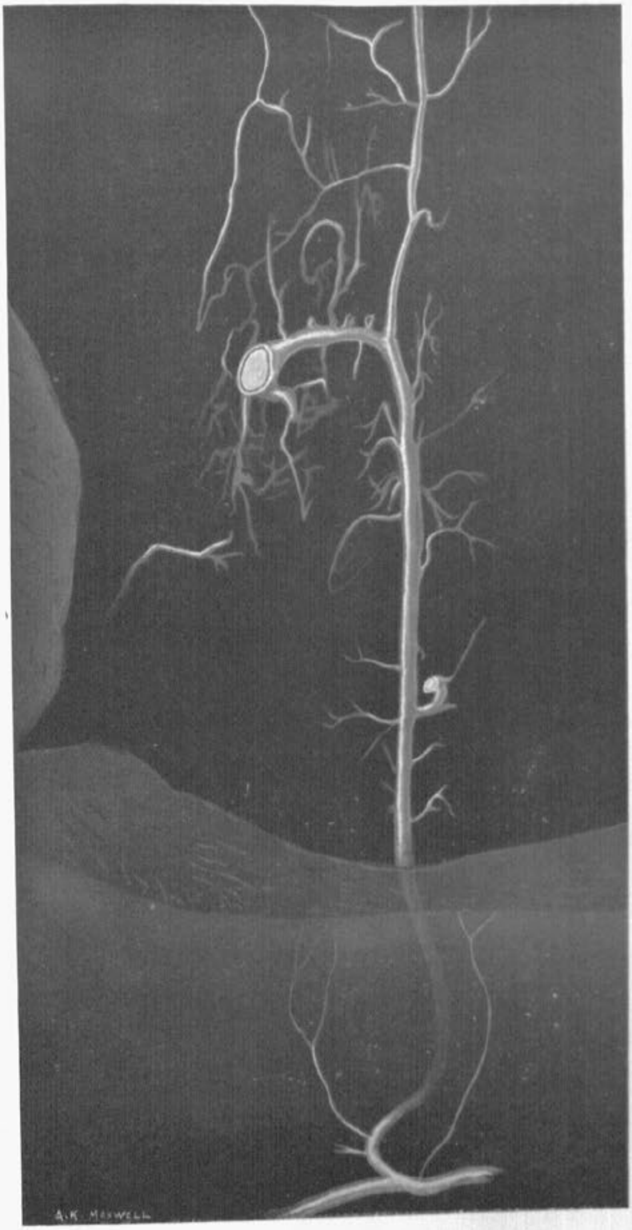


Fig. 8. A drawing ($\times 10$) of the large Thebesian vessel and its branches in a sheep's heart shown in Fig. 7. The vessel has two openings on the right side of the septum and runs subendocardially to the apex of the heart and pierces the wall of the right ventricle to join with an anterior interventricular vein.

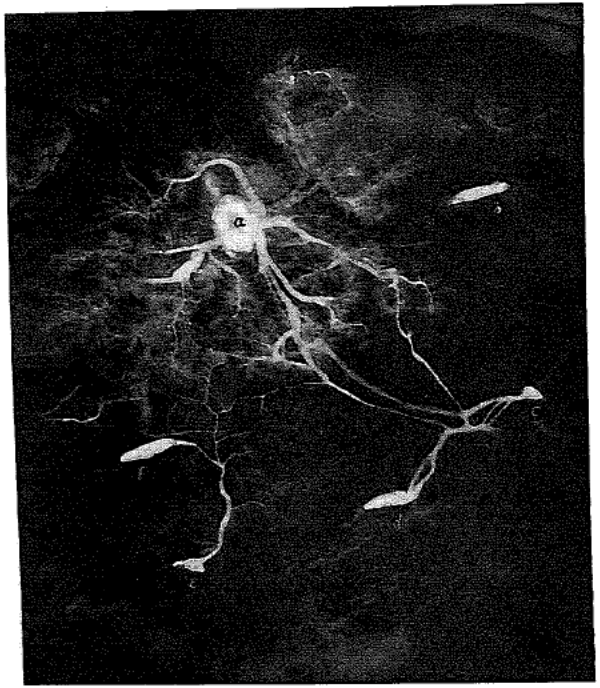


Fig. 9.

Fig. 10.

Fig. 9. Photograph (×4) of cleared preparation of the interventricular septum of a sheep's heart. Chrome yellow gelatine was injected into the Thebesian orifice *a* (covered by a plug of mass) and, filling the surrounding vessels, issued from five neighbouring foramina *b* to *f*. The more superficial communicating channels are clearly seen; the deep communicating channels such as that between *a* and *b* are not visible in the photograph.

Fig. 10. A photograph (×4) of the right side of interventricular septum of a dog's heart showing 6 endocardial foramina *a* to *f* and the channels arising from them injected through the foramina with chrome yellow gelatine. Foramina *a*, *b* and *d*, are connected together by a wide branching channel and to this channel foramen *c* is also joined by two finer branches. The vessels arising from foramen *e* form a curiously shaped plexus.

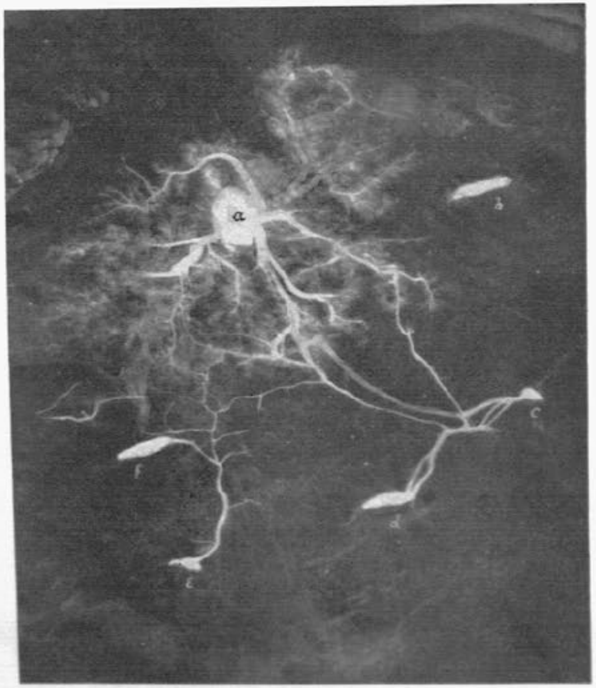
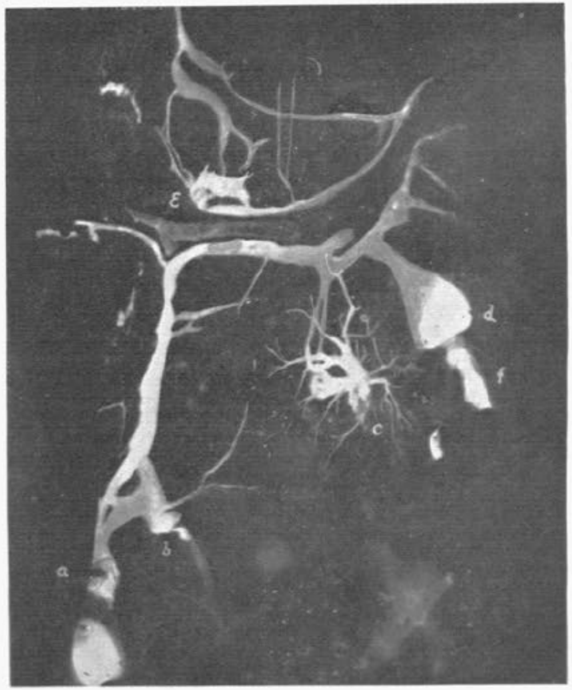


Fig. 9.



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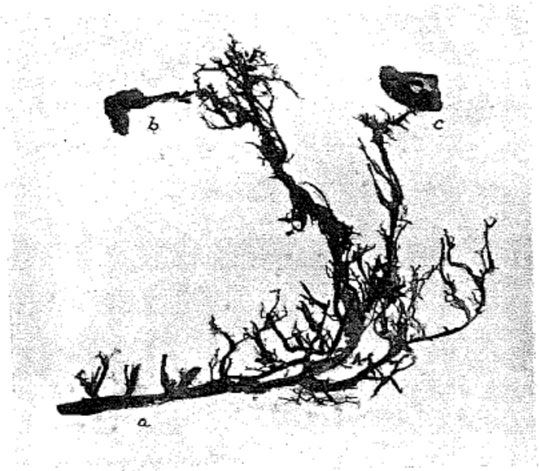

Fig. 11.

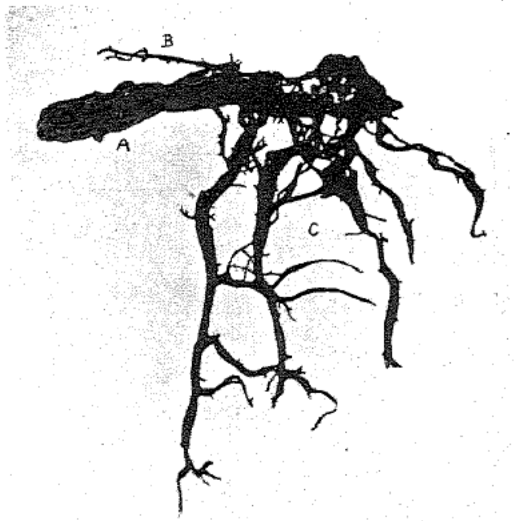

Fig. 12.

Fig. 11. Photograph ($\times 2$) of a corrosion preparation of a coronary vein *a*, celloidin injected, from the lateral wall of the left ventricle of a human heart. Most of the venous branches have been cut away to show clearly two branches opening into the left ventricle. The ventricular orifices are indicated by the celloidin plug, *b* and *c*.

Fig. 12. Photograph ($\times 7{\cdot}5$) of corrosion preparation (lateral view) of celloidin injected Thebesian vessels from the interventricular septum of a sheep's heart. From the orifice A, situated at the end of a groove on the right side of the septum, and partly filled by injection mass, a plexus of vessels, C, passes into the muscle. A superficial subendocardial branch, B is also injected.

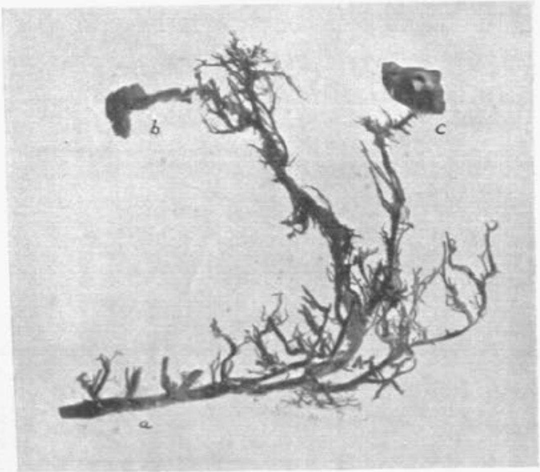

Fig. 11.

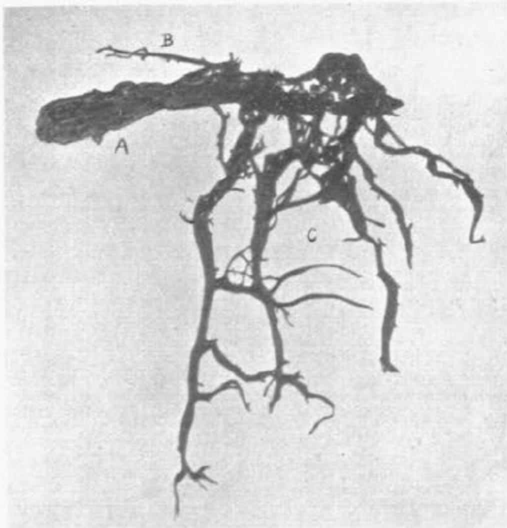

Fig. 12.

Fig. 11. Photograph (× 2) of a corrosion preparation of a coronary vein *a*, celloidin injected, from the lateral wall of the left ventricle of a human heart. Most of the venous branches have been cut away to show clearly two branches opening into the left ventricle. The ventricular orifices are indicated by the celloidin plug, *b* and *c*.

Fig. 12. Photograph (× 7·5) of corrosion preparation (lateral view) of celloidin injected Thebesian vessels from the interventricular septum of a sheep's heart. From the orifice A, situated at the end of a groove on the right side of the septum, and partly filled by injection mass, a plexus of vessels, C, passes into the muscle. A superficial subendocardial branch, B is also injected.